Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

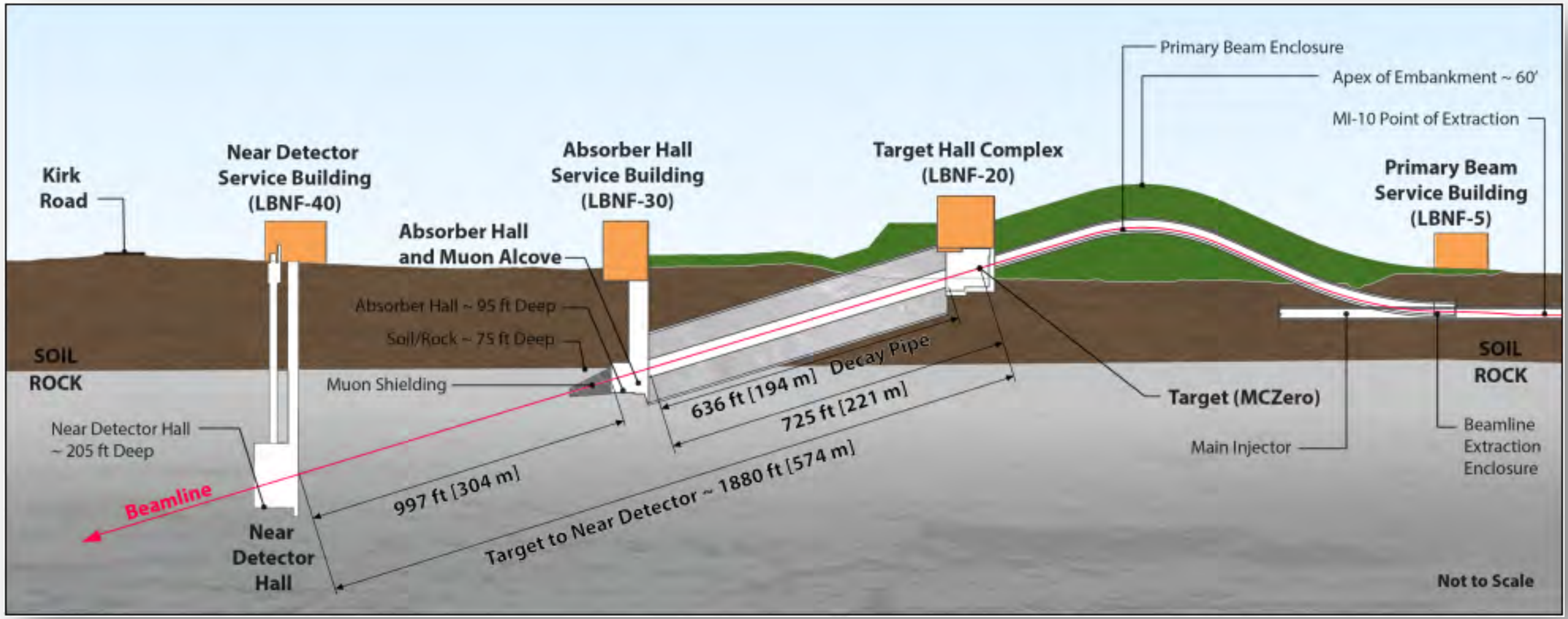
Optimization of LBNF Support Modules

Nicola Solieri

Final presentation

23 August 2016

Horn Systems Scope

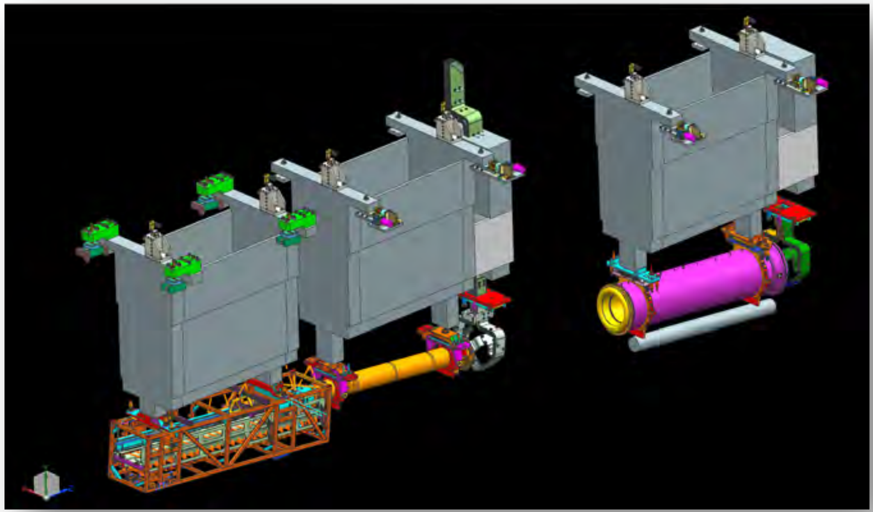


- Horn Systems are located at the near site target hall.
- Current optimization efforts → 3 horns and support structures

Importance of support modules

- Support and positioning of horns and target carrier.

- Intensely radioactive environment in the target chase



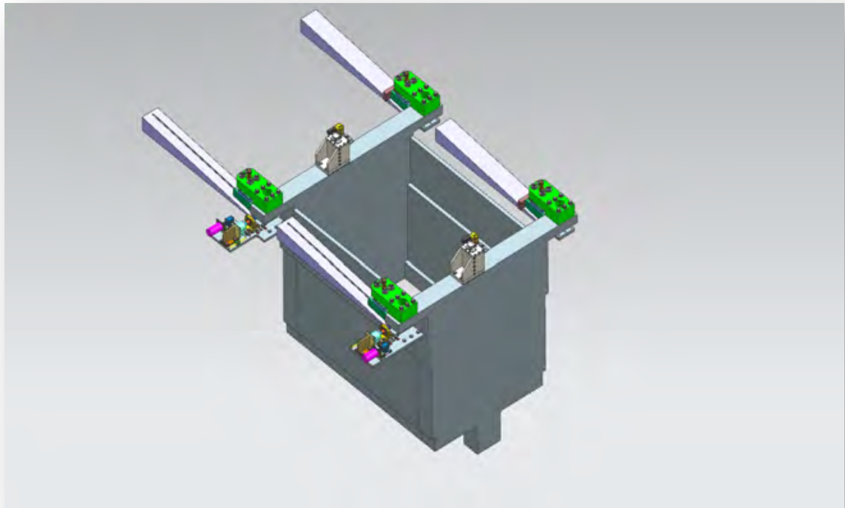
  - Radiation shielding
  - Remote control of horn position
  - Remote connection and disconnection of utitilities

Module structure

- Rectangular boxes open at the top for shielding block insertion.

- A36 steel construction

- Stainless steel in case of contact with water

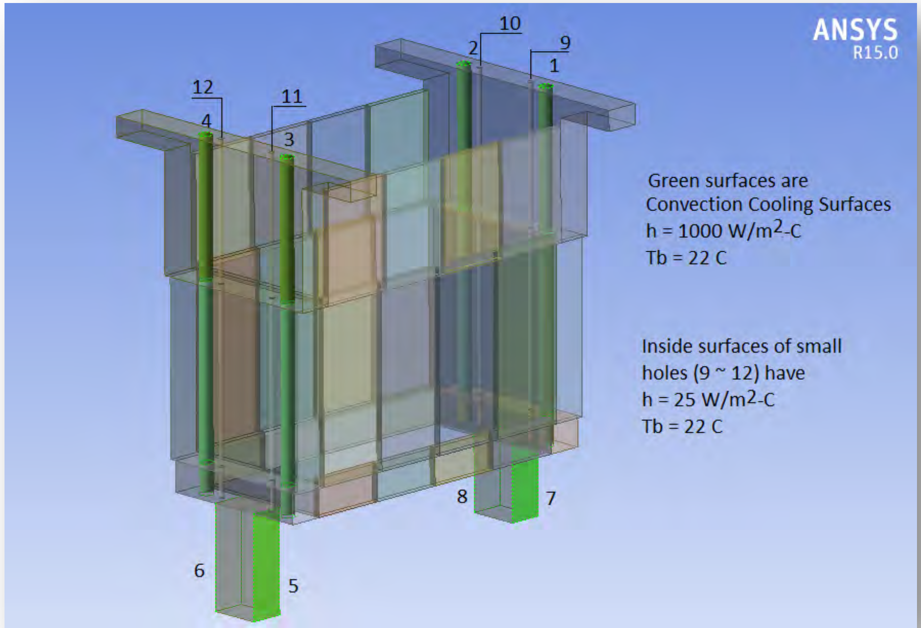


- Must be designed as “life of facility” components

- Must inferface with the target chase utilizing the remote positioning mechanisms that have already been designed.

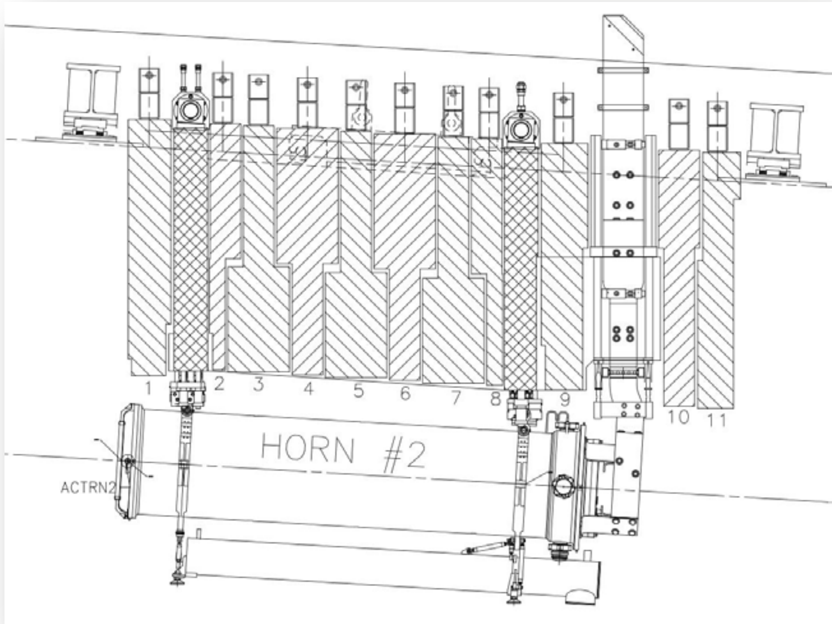
Known Module Concerns

- Shielding block temperature
- Thermal expansion / cooling affects accuracy of horn positioning
- Design solutions
  - Control rod construction to be Invar for low CTE.
  - Heat dissipating devices



Reference design and requirements

- NuMI module design used for reference.
- Shielding block is divided in “T-blocks”
- No line of sight from the top to the bottom of the module
- Number of blocks n chosen as a compromise between radiation shielding and block temperature.

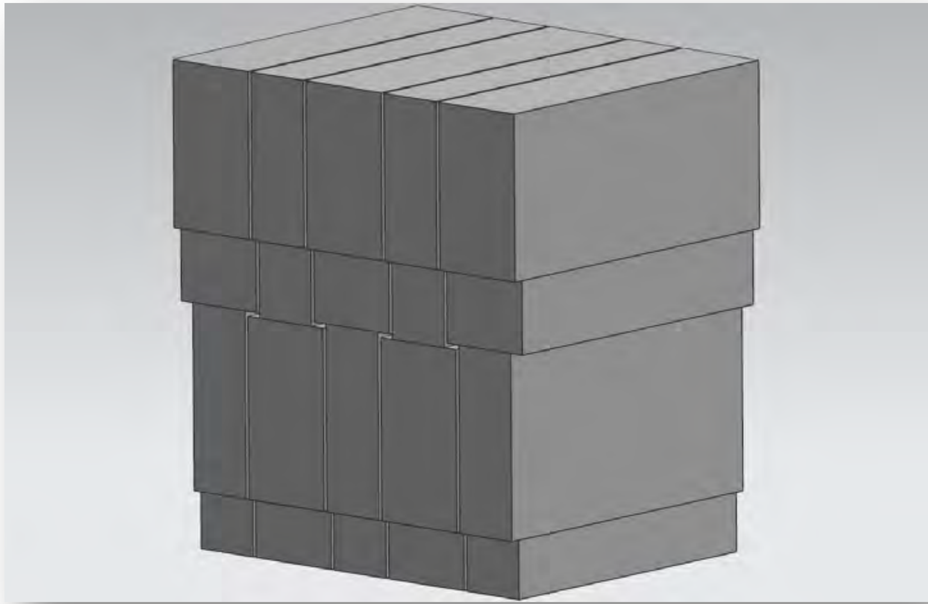


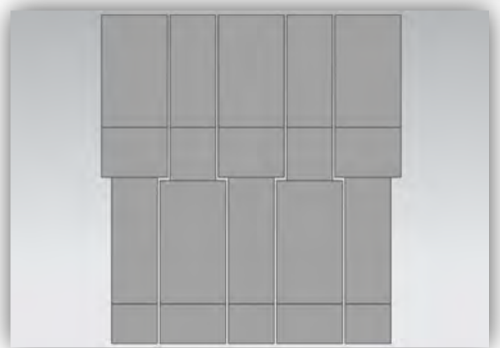
- n ↑ → Block thickness ↓
  - Surface area ↑ → Heat dissipation ↑
  - Radiation shielding ↓

T-block assembly design

- Two block types required in order to fit inside the module.

- ¾ ” lateral clearance required for ease of handling and better heat dissipation





Fermilab

Finite Element Analysis of Modules

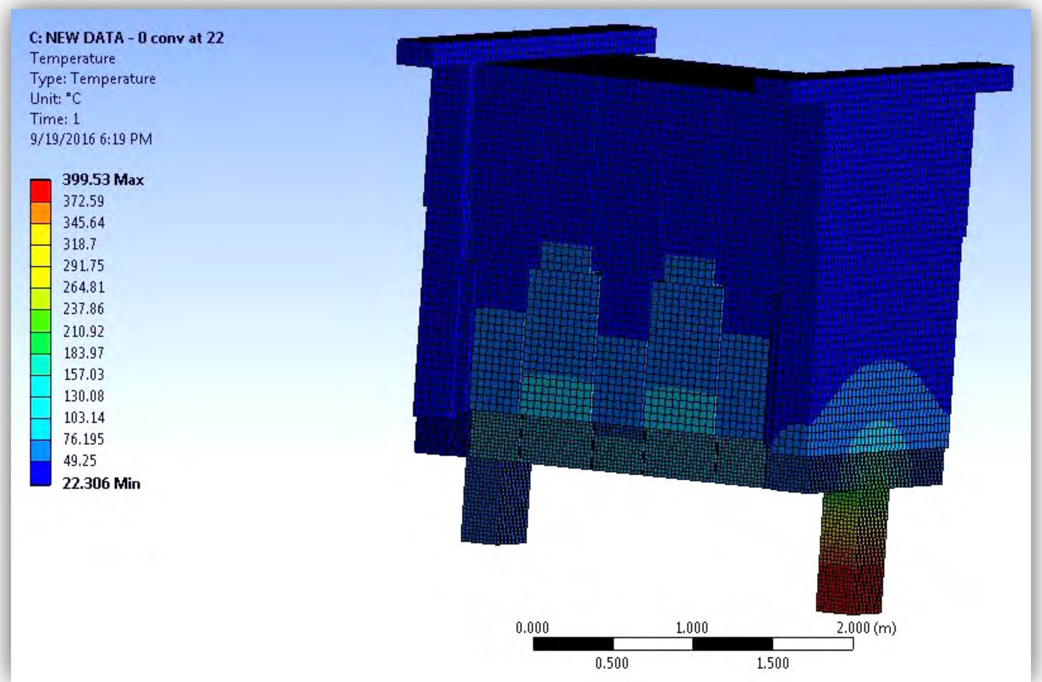
Finite Element Analysis of Modules

- Modules analyzed at all beam energies to ensure life of facility design.
  - 60, 80 & 120 GeV.

- Large deviations from installation temperature

↓

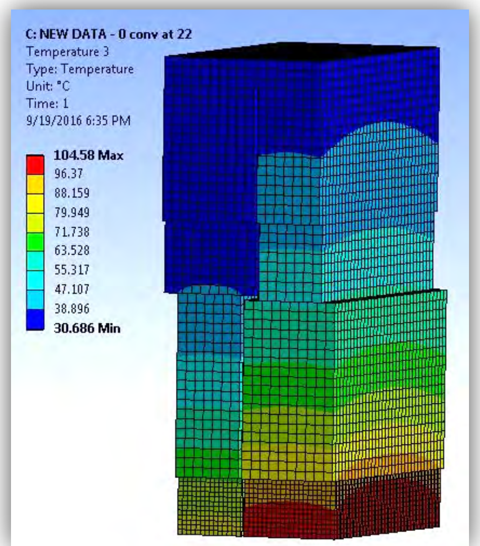
Horn misalignment



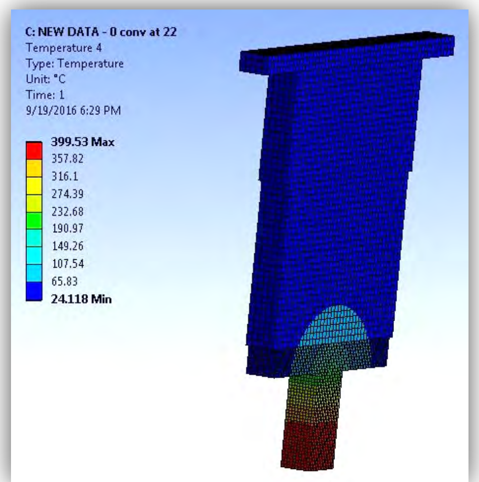
Finite Element Analysis of Modules

Two areas to focus on:

- T-block assembly



- Downstream end wall's "stalactite"



Finite Element Analysis of Modules

Details of "Convection"

Scope	
Scoping Method	Geometry Selection
Geometry	192 Faces
Definition	
Type	Convection
Film Coefficient	10. W/m²·°C (ramped)
Ambient Temperature	22. °C (ramped)
Convection Matrix	Program Controlled
Suppressed	No

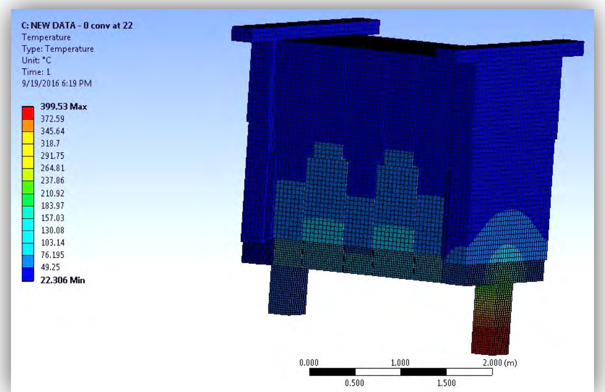
Problem!

ANSYS Steady State Thermal does NOT account for variations in air temperature

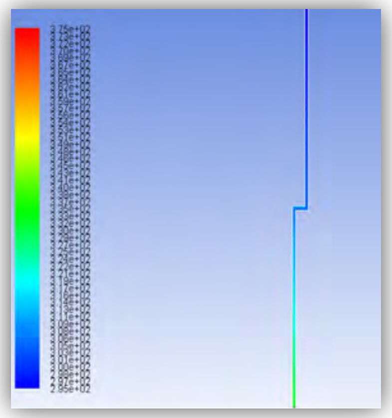
A more complex simulation is needed

Finite Element Analysis of Modules

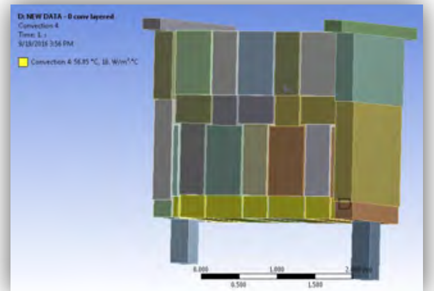
- First approach: iteration

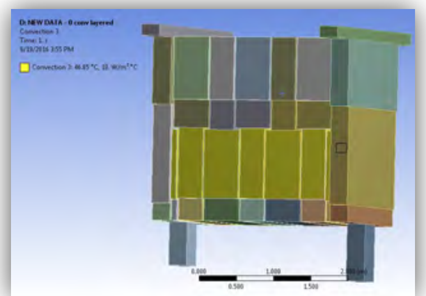


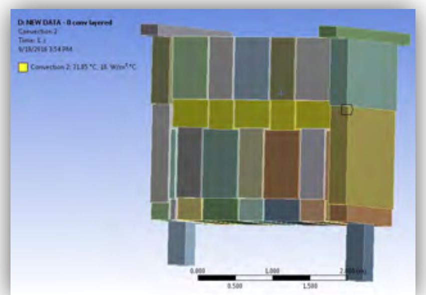
Steady state thermal analysis

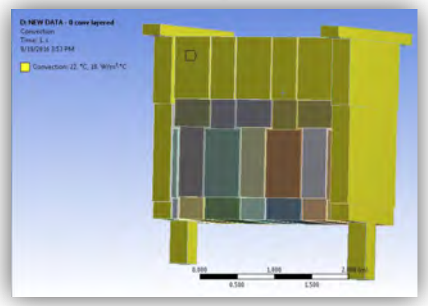


Fluent air analysis



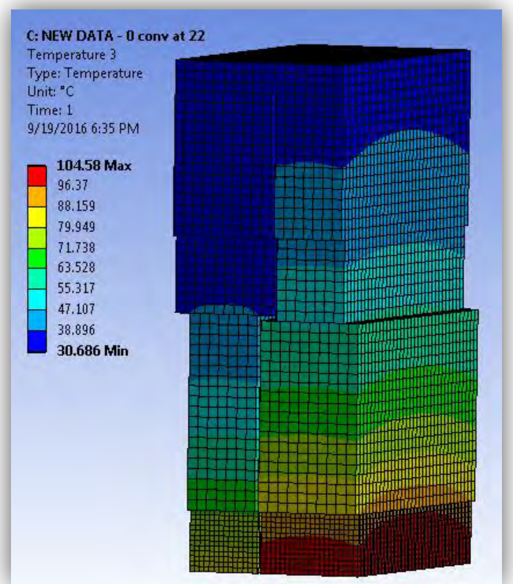




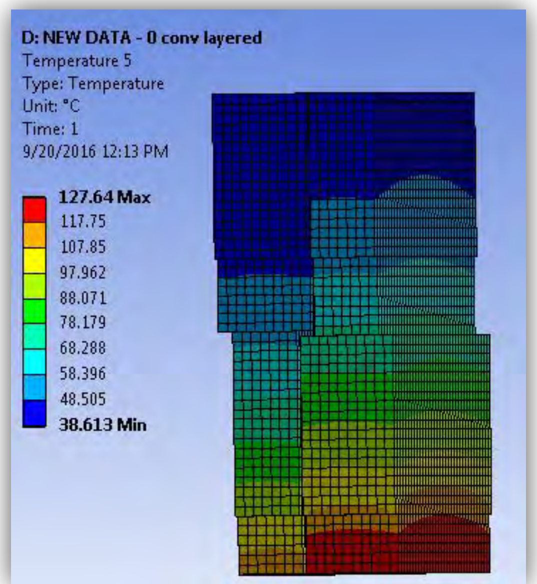


Ambient temperature values layered in Steady State Thermal

Finite Element Analysis of Modules



Before iteration



After 2 steps

That's a 23°C difference!

As expected, air state is a key factor. We need an even better model

Finite Element Analysis of Modules

- Second approach: 2D CFD analysis

- Key assumption
  Block width is > 5 times its thickness

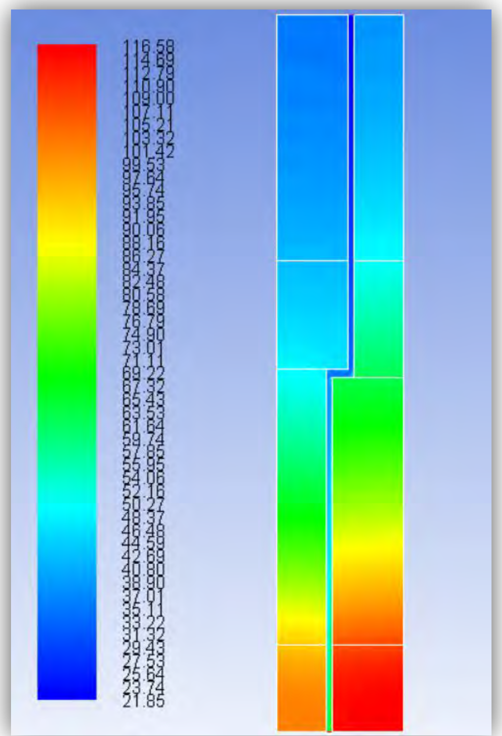
↓

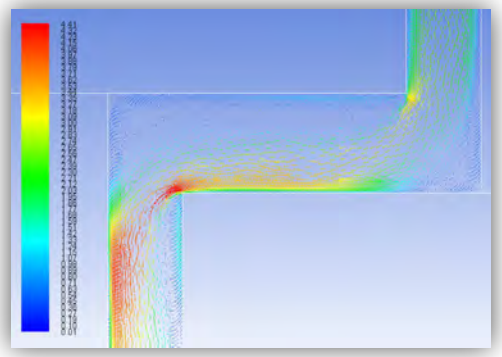
A 2D model is both physically accurate AND conservative

- The benefits are:
  – Comprehensive model: Conduction within the metal + Airflow in the gaps
  – More accurate analysis
  – Computationally convenient

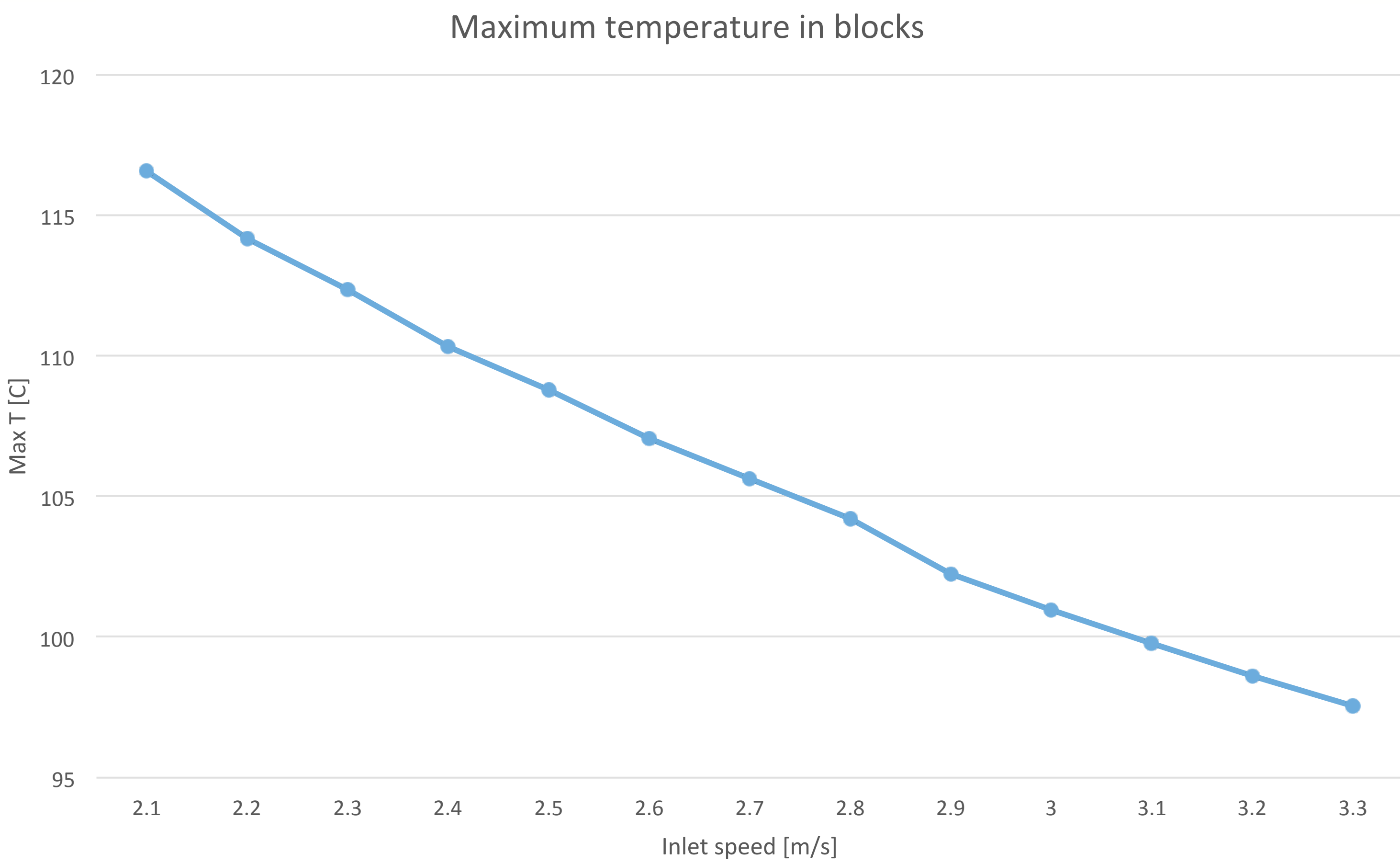
Finite Element Analysis of Modules

- Many aspects of the problem can be simultaneously analyzed using this simulation:
  - T-block temperature
  - Airflow properties (i.e. velocity, temperature, absence of reversal)
  - Effect of boundary condition variations





Finite Element Analysis of Modules



A 1.1m/s difference in air speed yields a 20 Deg. C temperature reduction

Finite Element Analysis of Modules

- Now we have 3 methods to analyze the thermal behavior of any given t-block assembly:
  - Steady state temperature analysis
  - Steady state + fluent iteration
  - Fluent 2D analysis

- Each one has its own set of pros and cons

- A full 3D CFD analysis will probably be required in the final design stage

Cold plate design and analysis

Cold plate design

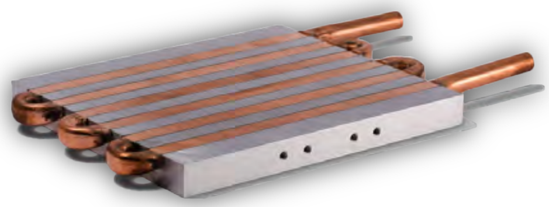
- Temperature reached in stalactite is too high: positioning accuracy is heavily affected.
- We need a way to remove heat from that area

- Cold plates are the obvious design choice

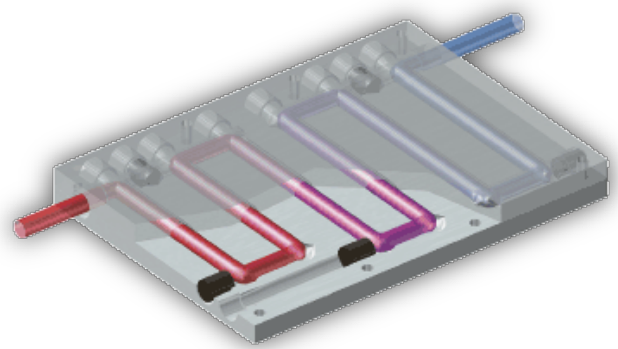
Cold plate design

- Two possible cold configurations taken into consideration:

  – Formed Tube Cold Plate (FTCP)
    + Simple design
    + Low cost
    - Poor performance (tube wall / plate contact resistance)

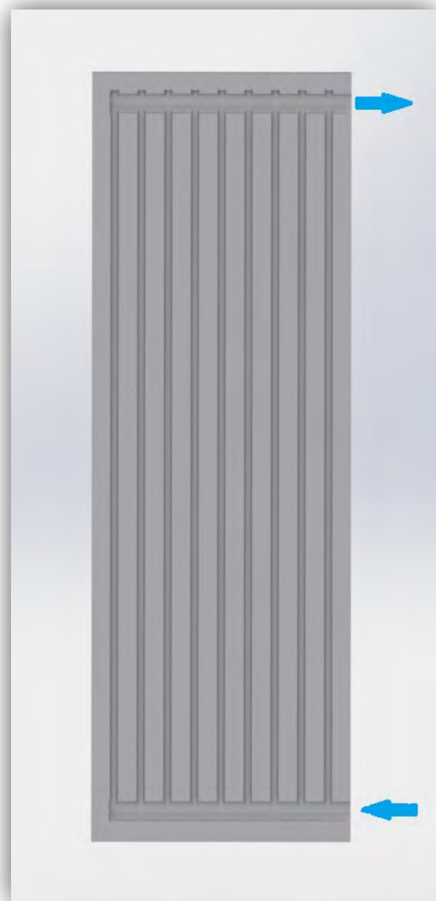


  – Deep Drilled Cold Plate (DDCP)
    + Better performance
    - Slightly higher manufacturing cost

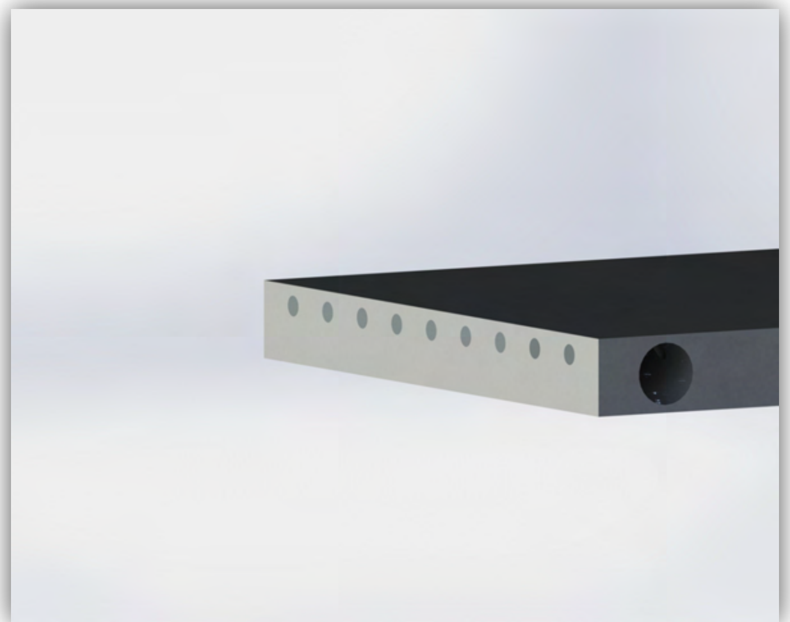


Cold plate design

- Key features:
  - 2 distribution channels + 9 connection channels
  - No copper → Aluminum construction
  - Water fed from bottom to maximize ΔT
  - Asymmetric design
  - Designed and tested for water flow rates between 10 l/min and 40 l/min

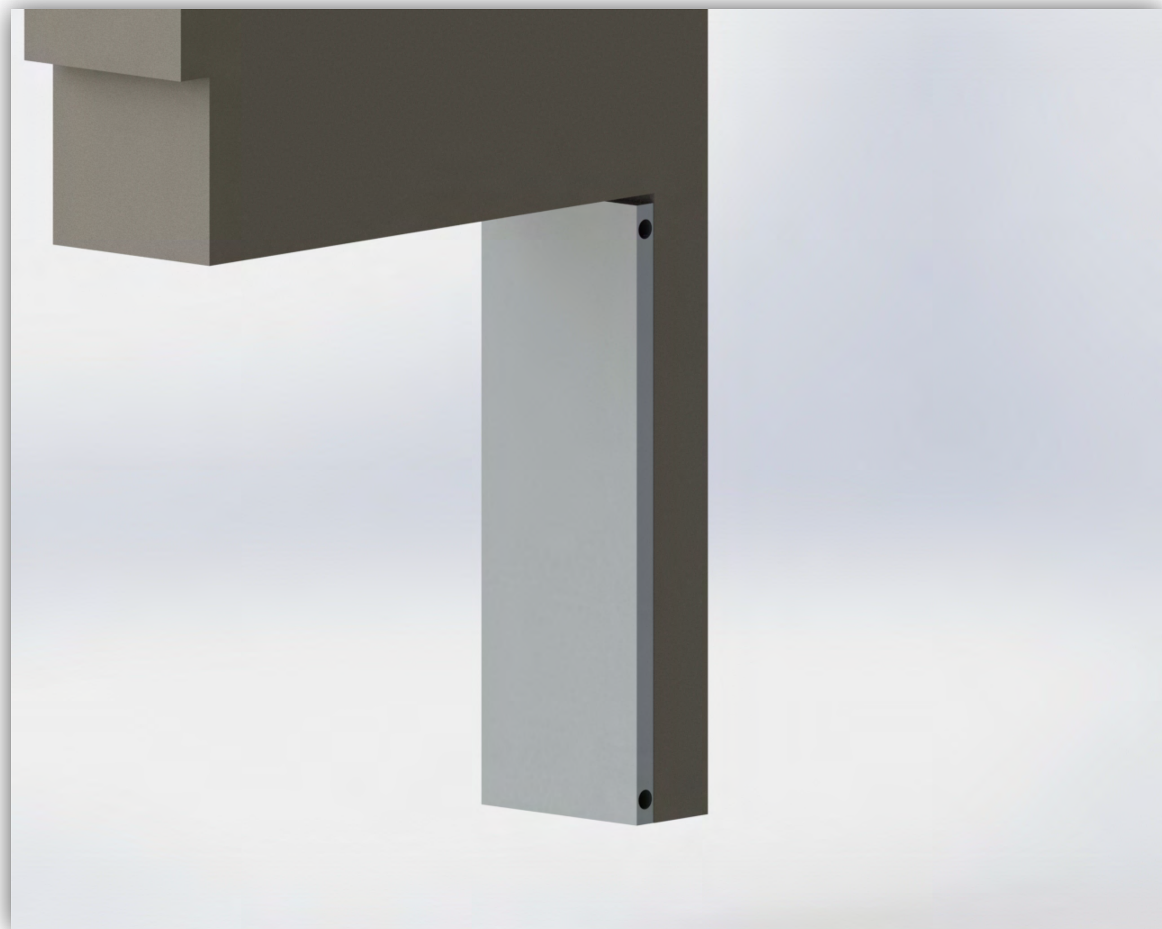


Cold plate design



Welded plugs to avoid leakage

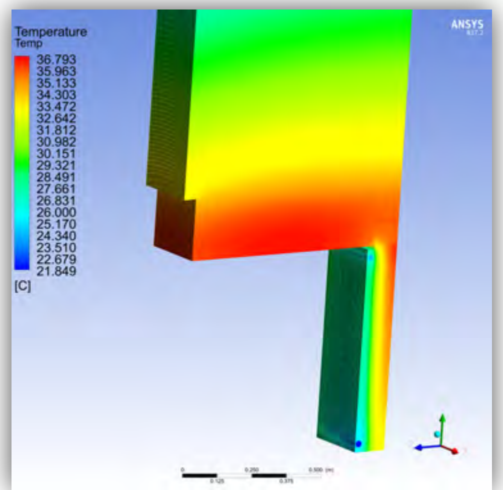
Cold plate design

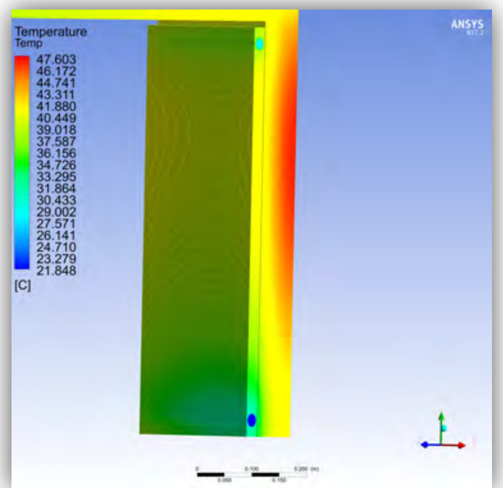


Cold plate installed on stalactite's side

Cold plate analysis

- 3D CFD analysis using ANSYS CFX:
  - Water flow
  - Parametric analysis
  - Temperature



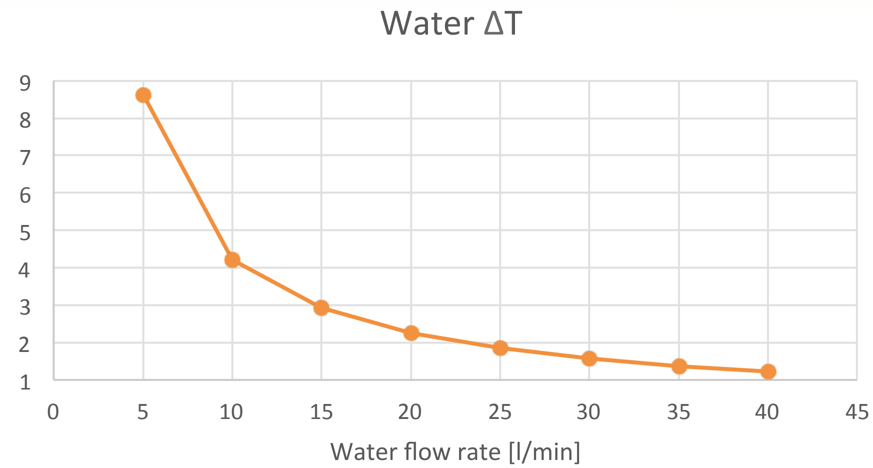


- Without cold plates the maximum temperatures are:
  - Stalactite → 325°C
  - Low end wall → 145°C

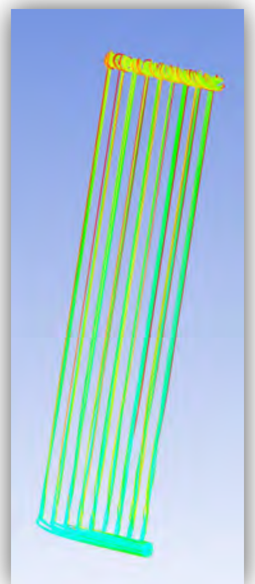
Cold plate analysis

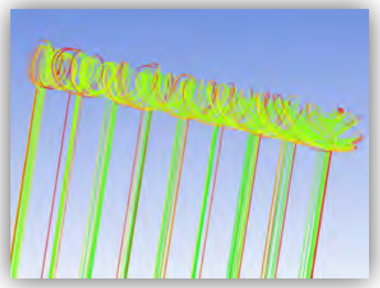
CFD analysis validation:

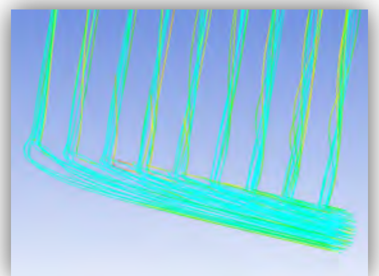
- Conceptual water ΔT is consistent with calculations by hand



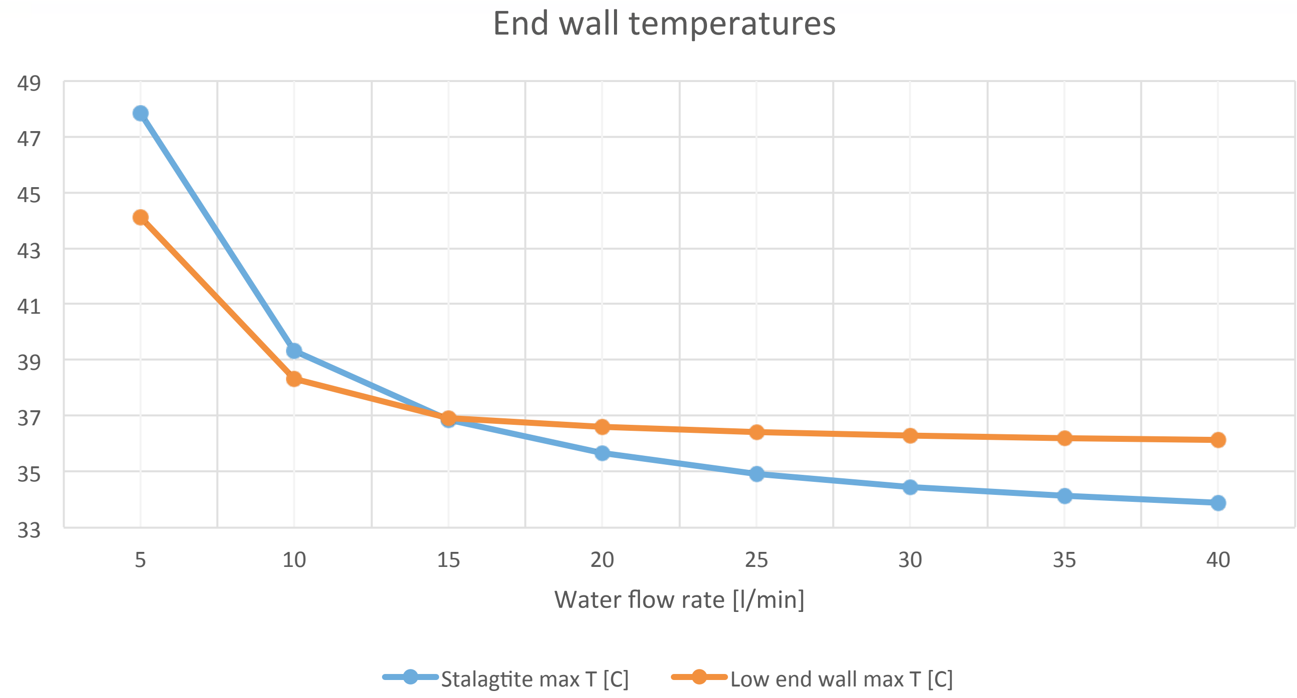
- Absence of anomalies in water streamlines







Cold plate analysis

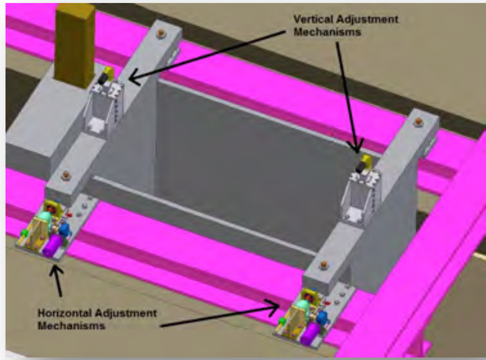


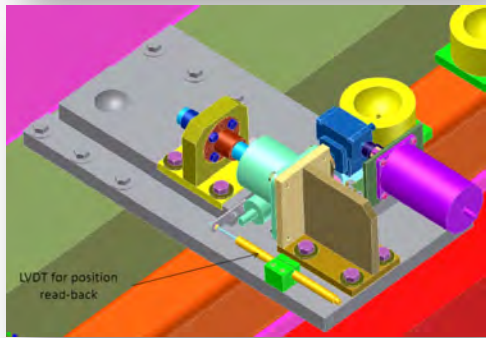
- Diminishing returns behavior was expected.
- Increasing water flow rates over 15 l/min is not justified by the incremental temperature reduction

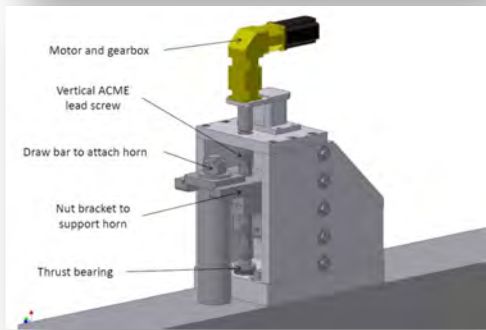
Module connection to horn

Module connection to horns

- The horn is adjusted with respect to the module for vertical and pitch alignment.
- The modules fix the horn with respect to the beamline in the other degrees of freedom







Module connection to horn

- The horn is connected to the module through a vertical Invar rod inserted in the module end walls.

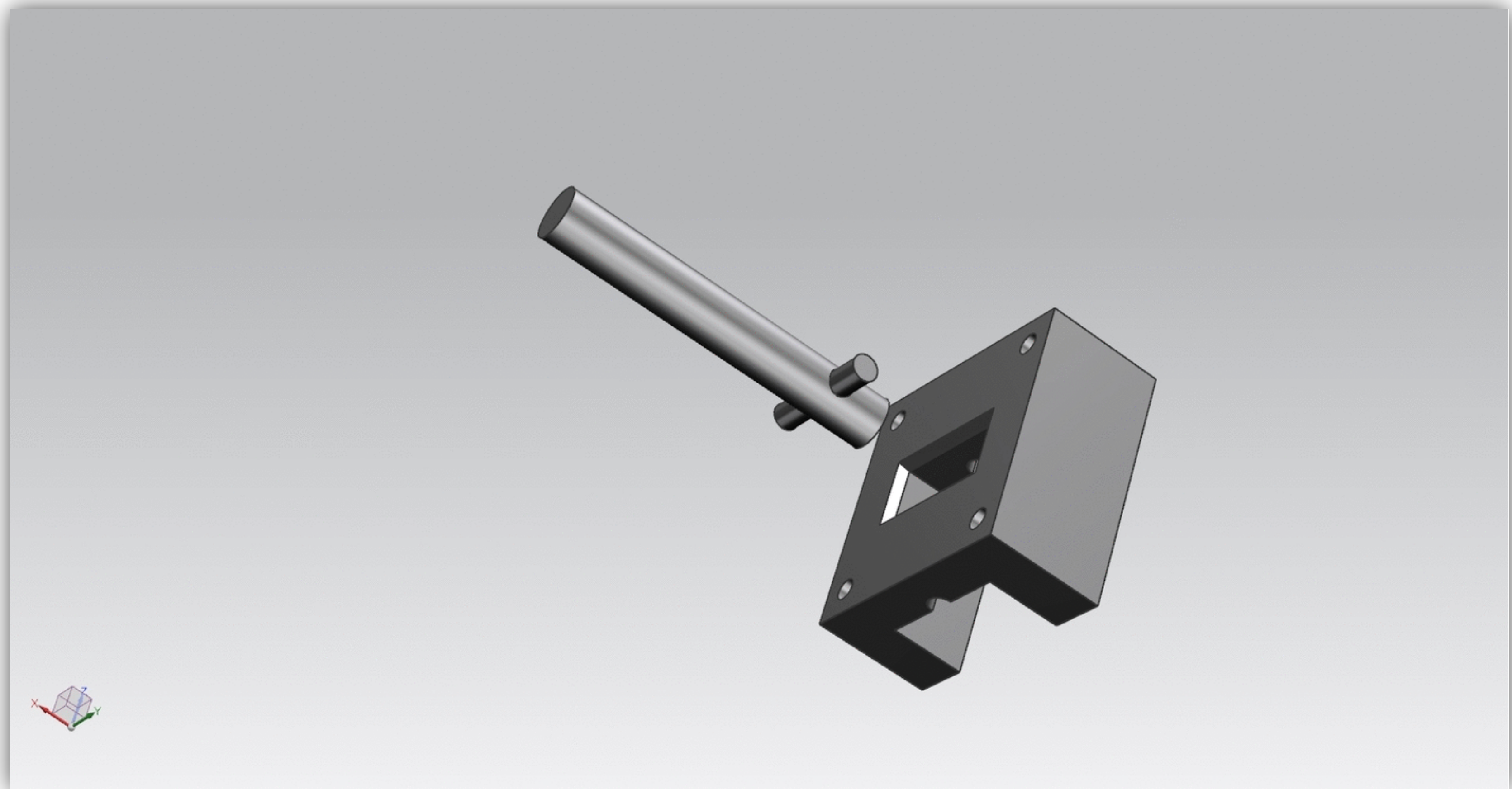
- Previous designs → Threaded connection

Problem!

Sliding contact
+
Corrosive environment
} Galling

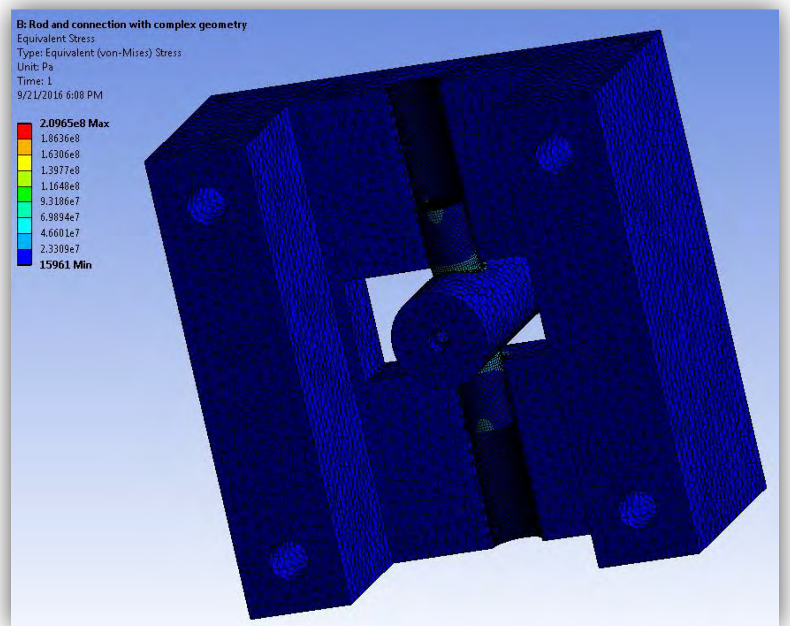
- The new proposed design eliminates this problem

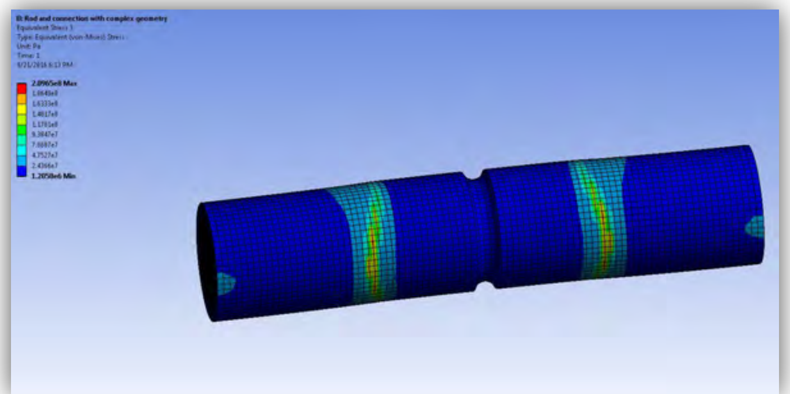
Module connection to horn



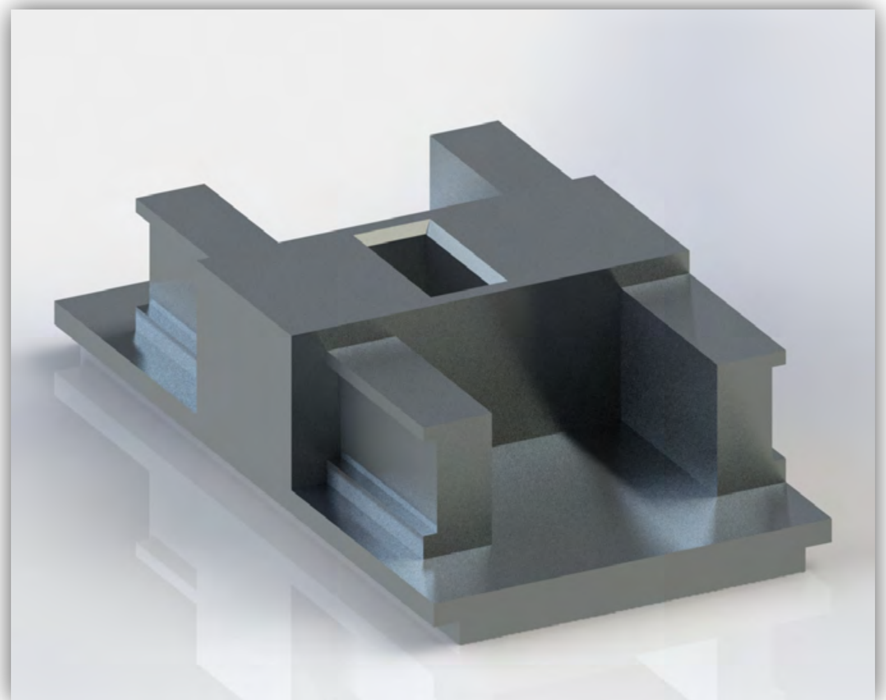
Module connection to horn

- Mechanism analyzed using ANSYS Steady Structural
  - 209 MPa peak stress in horizontal rod
  - Safety Factor SF = 2.5
  - Design is easily scalable if higher SF is required

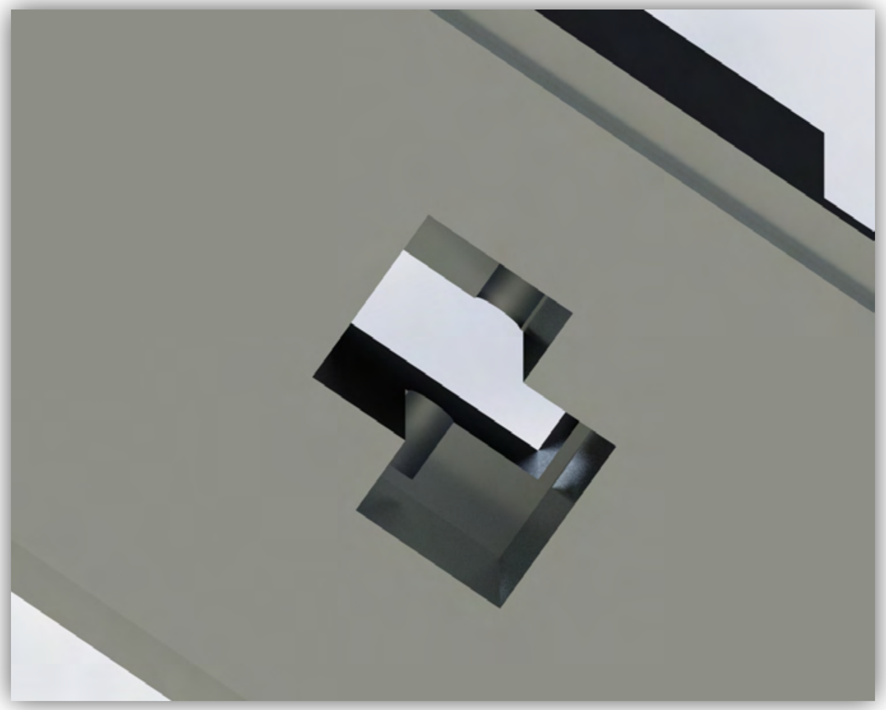




Module connection to horn



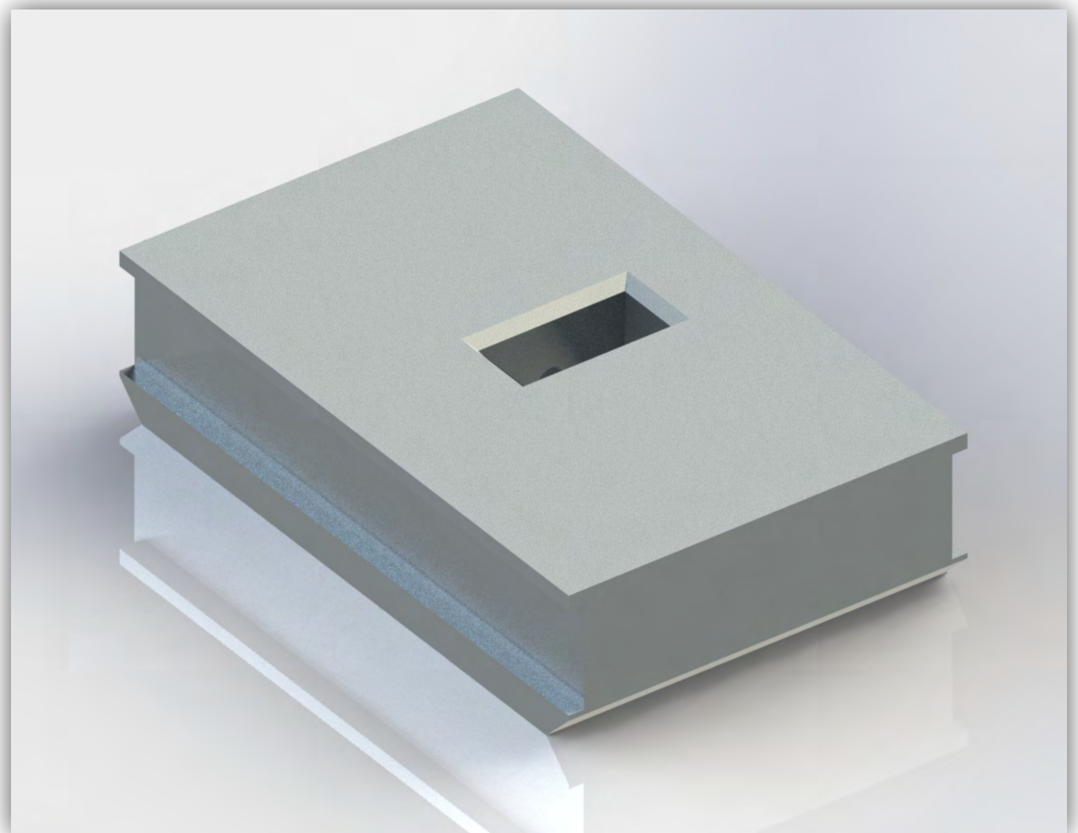
Downstream horn connection



Additional feature on the bottom

Design can be modular

Module connection to horn



Upstream horn connection

Thanks for your attention